

Effect of tillage, residue and nitrogen management on radiation interception, radiation use efficiency and evapotranspiration partitioning

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ABSTRACT

In this study, we have evaluated the effect of different tillage (conventional tillage (CT) and no tillage (NT)), residue (with crop residue mulch (R+) and without residue (R0)) and nitrogen (60, 120 and 180 kgN ha⁻¹) interaction for radiation interception, radiation use efficiency (RUE), evapotranspiration (ET) partitioning and yield of wheat in a split-split plot design for 2017-18 and 2018-19. Results showed that Leaf Area Index (LAI), Leaf area duration (LAD), Total intercepted photosynthetically active radiation (TIPAR), Grain and Biomass yields were higher in R+ during both the years of study. With increasing N-doses LAI, LAD, TIPAR, RUE, grain and biomass yields increased and extinction coefficient decreased significantly in both the years. Fraction intercepted photosynthetically active radiation (fIPAR) followed a similar trend with LAI. Seasonal ET was partitioned into soil evaporation (Ep) and crop transpiration (Tp) to take into account the productive transpiration effects on crop growth and yield. It was found that NT and residue could reduce Ep (6% and 5.6%) and increased Tp (2.6% and 2.4%) over CT and no mulch treatments, respectively. With higher N-dose, Ep decreased while Tp increased significantly. Thus besides higher nitrogen doses, NT and crop residue mulching could be a better strategy to harness higher radiation interception *vis-a-vis* higher crop productivity.

Key words : Conventional tillage, no tillage, LAI, RUE, soil evaporation, crop transpiration

Conventional agricultural practices involving indiscriminate tillage practices and imbalanced use of fertilizers and agrochemicals have become a matter of serious concern with respect to degradation of land resources, reduction of biodiversity and low efficiency of inputs (Boatmann *et al.*, 2007). Conservation agriculture (CA), on the other hand, involving reduced tillage, residue retention and crop rotation have beneficial impacts on the global environment (soil, air, water and biodiversity) compared to traditional agriculture (Kassam *et al.*, 2010). These practices along with other best management practices like raised bed planting for water saving and better establishment offer particular opportunities in the maize-wheat in South Asia (Fredrich and Gustafson, 2007). Das *et al.* (2018) reported that practicing conservation agricultural practices could improve the yield and water productivity in maize-wheat system in the Indo-gangetic Plain region. Therefore the conservation agriculture practices are targeted to achieve sustainability by implementation of management practices which would minimize environmental degradation and improve resource use efficiency. While most of the research focuses on the photosynthetic efficiency and

harvest index of crops, literature on the modification of microclimate by changing management practices that can affect the yield is scanty (Pragya *et al.*, 2018; Wakchaure *et al.*, 2015).

With this background, the objective of this study was to explore the pattern of radiation interception and radiation use efficiency under different conservation agriculture treatments and comparing them with conventional practices. This study was also aimed at partitioning of evapotranspiration into utilizable (transpiration) and non-utilizable (evaporation) water resource used under conservation *vis-à-vis* conventional agricultural systems.

MATERIALS AND METHOD

Experimental details

The experiment was conducted for two consecutive years (2017-18 and 2018-19) on wheat cultivar HD-2967 at the ICAR-Indian Agricultural Research Institute, New Delhi (28°37' N, 77°12' E) in *rabi* season (24th Nov to 16th April). New Delhi is coming under sub-tropical semi-arid climate with a mean annual rainfall of 651 mm. The surface soil (0-

15 cm) is sandy loam in texture, with an average bulk density of 1.58 Mg m⁻³; pH 7.8 (1:2.5 soil: water suspension); organic C, 4.2 g kg⁻¹; Total N, available (Olsen) P and available K content of 0.032%, 7.1 kg ha⁻¹ and 281 kg ha⁻¹, respectively.

The experiment was conducted in a split-split plot design with two levels of tillage i.e. Conventional tillage (CT) and No Tillage (NT) as main plot factor, two levels of residue mulching (maize residue @ 5tha⁻¹ (R+) and without residue (R0)) as sub plot factor, and three levels of nitrogen i.e. 50% (N₆₀), 100% (N₁₂₀) and 150% (N₁₈₀) of the recommended dose of nitrogen in wheat as sub sub-plot factor, which correspond to 60, 120 and 180 kg N ha⁻¹, respectively. There were three replications and the size of sub-sub plot was 4.5m × 5m.

Weather parameters

The weather parameters were obtained from the agrometeorological observatory situated adjacent to the field. Different weather parameters like mean minimum and maximum temperatures, rainfall, morning and evening relative humidity, wind speed, bright sunshine hours and pan evaporation were recorded on daily basis.

Crop parameters

Plant samples (1m row length) were collected from the fields at regular intervals to determine the temporal variation in plant biomass on dry weight basis (dried in oven at 70°C till constant weight) and expressed in t ha⁻¹.

Leaf area index (LAI) and leaf area duration (LAD)

LAI was measured in all the three replications using LAI-2000 Plant Canopy Analyzer (LI-COR, USA) at weekly intervals (between 11:30 and 12:00 hours IST) for two consecutive years. LAD was computed using the following relationship:

$$LAD = \sum ((LAI_{n-1} + LAI_n) / 2) (t_n - t_{n-1})$$

Where, LAI_n and LAI_{n-1} correspond to LAI at sampling time t_n and t_{n-1}, respectively.

Grain and biomass yield

Grain yield along with the harvest biomass was obtained at the time of crop harvesting from an area of 2 × 2 m² from each plot in three replications and the yield was expressed as kg ha⁻¹. The harvest biomass was obtained after air drying the plant obtained from that area.

Radiation characteristics

The photosynthetically active radiation (PAR)

measurements were taken using Line quantum sensor LI-191SA (LICOR Inc., Lincoln, NE, USA) (between 11:30 and 12:00 hours IST) from the top and bottom of wheat canopy on the same day when LAI observations were taken. The fraction intercepted photosynthetically active radiation (fIPAR) for a particular day is obtained from the following formula:

$$fIPAR = (I_o - I_t) / I_o$$

where, 'I_o' is incident radiation and 'I_t' is transmitted radiation through the canopy.

Daily insolation was calculated using Angstrom equation (using coefficients a=0.32, b=0.46), where bright sunshine hours observation was used as an input. Subsequently, incident PAR was calculated by multiplying a factor of 0.48 with the daily insolation values. Latter, daily intercepted PAR (IPAR) was estimated by multiplying incident PAR with fIPAR. Similarly, total IPAR (TIPAR) was obtained by integration of daily IPAR. The radiation use efficiency (RUE) was calculated by dividing total above ground biomass (g m⁻²) with the TIPAR (MJ/m²) for the whole crop duration (Pradhan *et al.*, 2014; Goyal *et al.*, 2018).

The canopy extinction coefficient (k) was computed from fIPAR and LAI following Monsi and Saeki (1953) equation.

Extinction coefficient was determined from the slope of the regression equation between LAI and ln(1 - fIPAR), when it is forced through zero.

Evapotranspiration

The potential evapotranspiration (ET₀) was calculated as per Penman and Monteith equation, (Allen *et al.*, 1998). Wheat crop ET (ET_c) was estimated by multiplying crop coefficient (K_c, FAO 56) under standard well-watered, fertilized and disease-free conditions.

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T+273} u_2 (e_0 - e_a)}{\Delta + \gamma (1 + 0.34 u_2)}$$

Where,

ET₀ - potential evapotranspiration in mm /day; R_n - net radiation at crop surface (MJ m⁻² hr⁻¹); G - soil heat flux density (MJ m⁻² day⁻¹); T - air temperature at 2 m height (°C); e_s - saturation vapour pressure (kPa); e_a - actual vapour pressure (kPa); u₂ - wind speed at 2m height (m s⁻¹); Δ - the slope of the vapour pressure curve (kPa °C⁻¹); γ - The psychrometric constant in (kPa °C⁻¹).

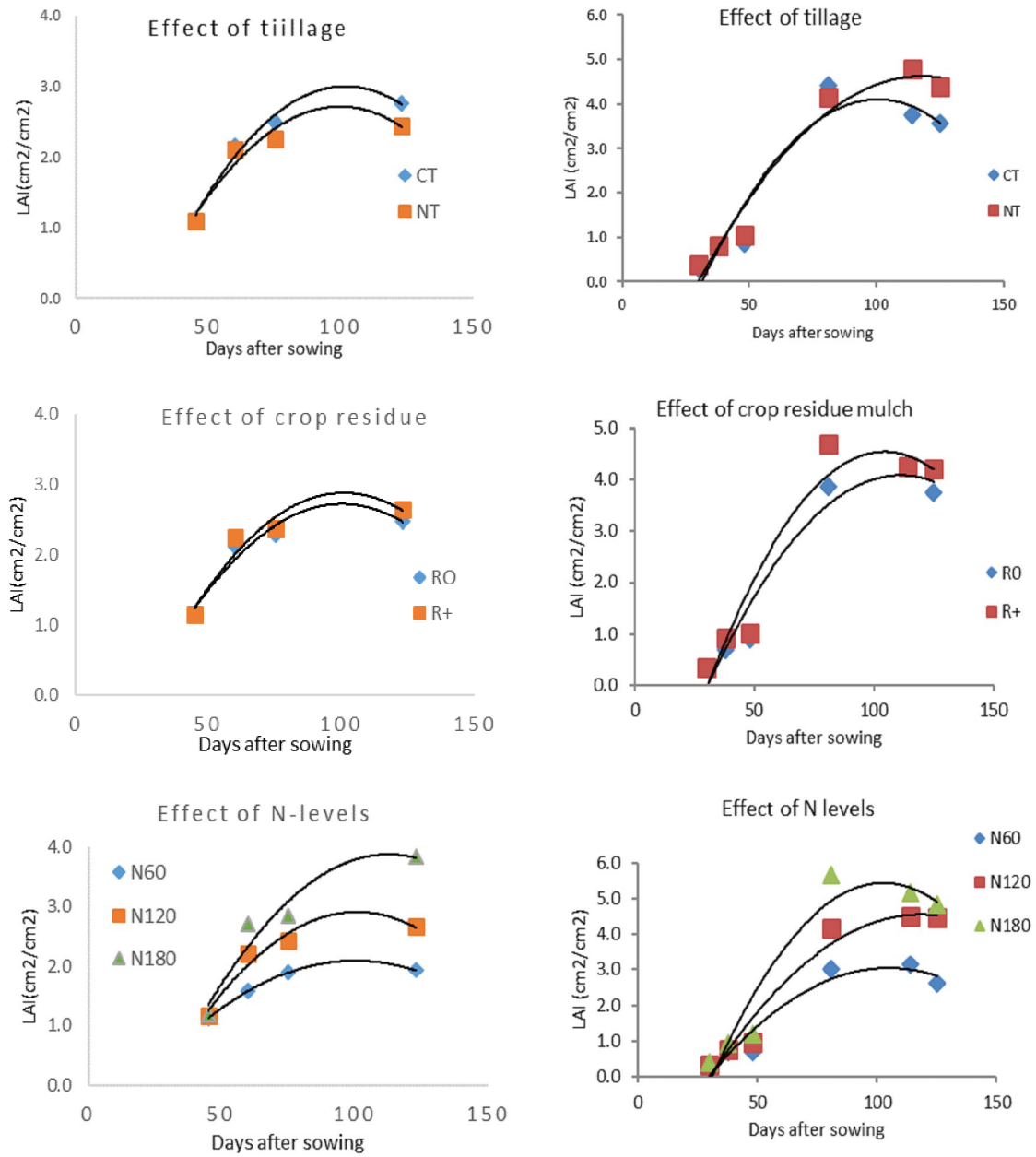


Fig.1: Leaf area index of wheat as influenced by tillage, residue and nitrogen management during the year 2017-18 and 2018-19.

The net radiation was evaluated from the following formula:

$$R_n = (1 - \gamma)(0.25 + 0.5 n/N) SO + (0.9n/N + 0.1)(0.34 - 0.14 e_a) \sigma T$$

Where,

T - the air temperature (K); r - the reflection coefficient (observed mean value, 0.24); n - the number of hours of bright sunshine per day (h); N - The total day length (h); SO is the extra-terrestrial radiation (MJ m⁻² day⁻¹); e_a - the vapour

pressure (kPa); σ - The Stefan-Boltzmann constant (4.903 × 10⁻⁹ MJ m⁻² K⁻⁴ day⁻¹)

Partitioning evapotranspiration

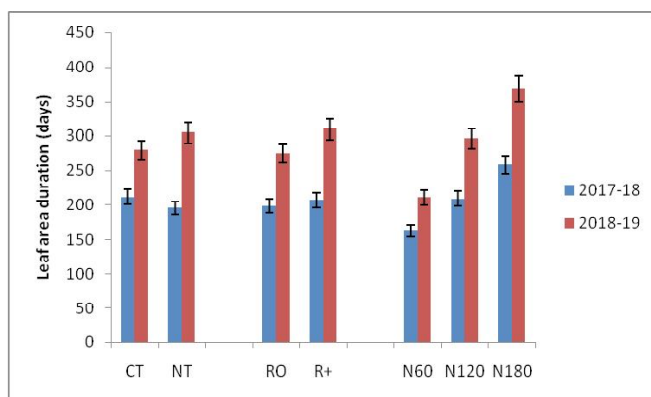
For partitioning ET_c into soil evaporation (E_p) and crop transpiration (T_p), the following formula (Ritchie 1972) was used,

$$E_p = ET_c \cdot \exp(-k \cdot LAI)$$

where, k is extinction coefficient.

Table 1: Monthly weather data of the study area

Month	Max. temp.(°C)		Min. temp.(°C)		Max. RH(%)		Min. RH(%)		Sunshine hours		Rainfall (mm)		Evaporation (mm)	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Nov	26.8	27.4	10.6	11.8	87.7	88.9	49	57.6	2.5	4.7	0.0	4.0	2.3	2.9
Dec	23.0	21.8	6.8	5.0	87.0	94.7	51	63.8	4.5	4.4	0.0	0.2	2.3	2.0
Jan	20.6	20.0	4.3	6.4	92.8	90.3	49.3	70.7	6.3	3.8	6.0	52.0	2.4	1.6
Feb	24.9	21.3	8.4	10.0	80.2	95.0	41.9	74.6	6.4	3.6	0.0	72.2	3.5	1.9
Mar	31.6	27.0	13.4	12.4	83.0	89.3	31.3	57.5	8.2	7.3	0.0	10.0	5.1	3.1
April	36.5	37.2	19.9	21.1	62.3	71.8	29.8	42.0	7.7	8.2	20.0	5.7	6.0	5.3

**Fig.2:** Leaf area duration of wheat as influenced by tillage, residue and nitrogen management.

Thereafter crop transpiration was calculated as

$$T_p = (ET_c - E_p).$$

RESULTS AND DISCUSSION

Weather

Monthly average maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sunshine hours, rainfall and evaporation during crop growth periods of wheat for the years 2017-18 and 2018-19 are presented in Table 1. The crop experienced a higher maximum temperature (December, January, February and March) in the year 2017-18 compared to the year 2018-19 by 1.2, 0.6, 3.6 and 4.6°C, respectively. During the year 2017-18, the crop received a total rainfall of 26 mm whereas, during the year 2018-19 the crop received a total rain of 144.1 mm. The average sunshine hour during the year 2017-18 (5.93 h) was higher than that of the year 2018-19 (5.33 h). The mean RH during the year 2018-19 (74.7%) was higher than that of the year 2017-18 (62.1%). So the crop

during the year 2017-18 was under high temperature and moisture stress than the year 2018-19.

Leaf area index (LAI) and Leaf area duration (LAD)

Leaf area index (LAI) followed an exponential relation with days after sowing (Fig. 1). LAI under CT and NT showed variable response over the years. Maximum LAI (LAI_{max}) was higher in CT (12.7%) than NT during 2017-18 whereas it was higher in NT (8.8%) than CT during 2018-19. Crop residue mulch (CRM) improved the LAI during both the years (by 6.5% and 10% in 2017-18 and 2018-19, respectively). Higher LAI_{max} in CT (2017-18) or NT (2018-19) is well correlated with higher yields in these treatments (Table 2). Higher LAI in CT is in agreement with Gajri *et al.* (1992) while Yin *et al.* (2016) observed that LAI with standing straw and NT was more than straw incorporated and straw removal treatments of CT. The LAI of wheat increased significantly with increase with increase in N-doses. Averaged over tillage and residue management, LAI_{max} with 180 kg N ha⁻¹ was higher than 120 and 60 kg N ha⁻¹ by 44.4% and 99%, respectively in 2017-18 and by 25.6 and 79.3%, respectively in 2018-19. Application of 120 kg N ha⁻¹ significantly improved LAI_{max} than that of 60 kg N ha⁻¹ by 37.8% and 42.7%, during the year 2017-18 and 2018-19, respectively. This increase in LAI with increase in N dose was due to increase in cell enlargement (McCree and Davis 1974); increased growth (Jones *et al.*, 1980) and increased photosynthetic activity of leaves (Openheimer, 1960) with increasing N-doses and is in agreement with Cox *et al.* (1993); Panda *et al.* (2004) and Pradhan *et al.* (2014).

The LAD during 2017-18 was higher in CT (by 8.2%) than that of NT whereas during 2018-19 it was higher in NT (by 9%) than that of CT (Fig. 2). CRM could increase the LAD in both the years (by 4% and 12.8%, in 2017-18 and 2018-19, respectively) than no-mulch treatment. LAD under

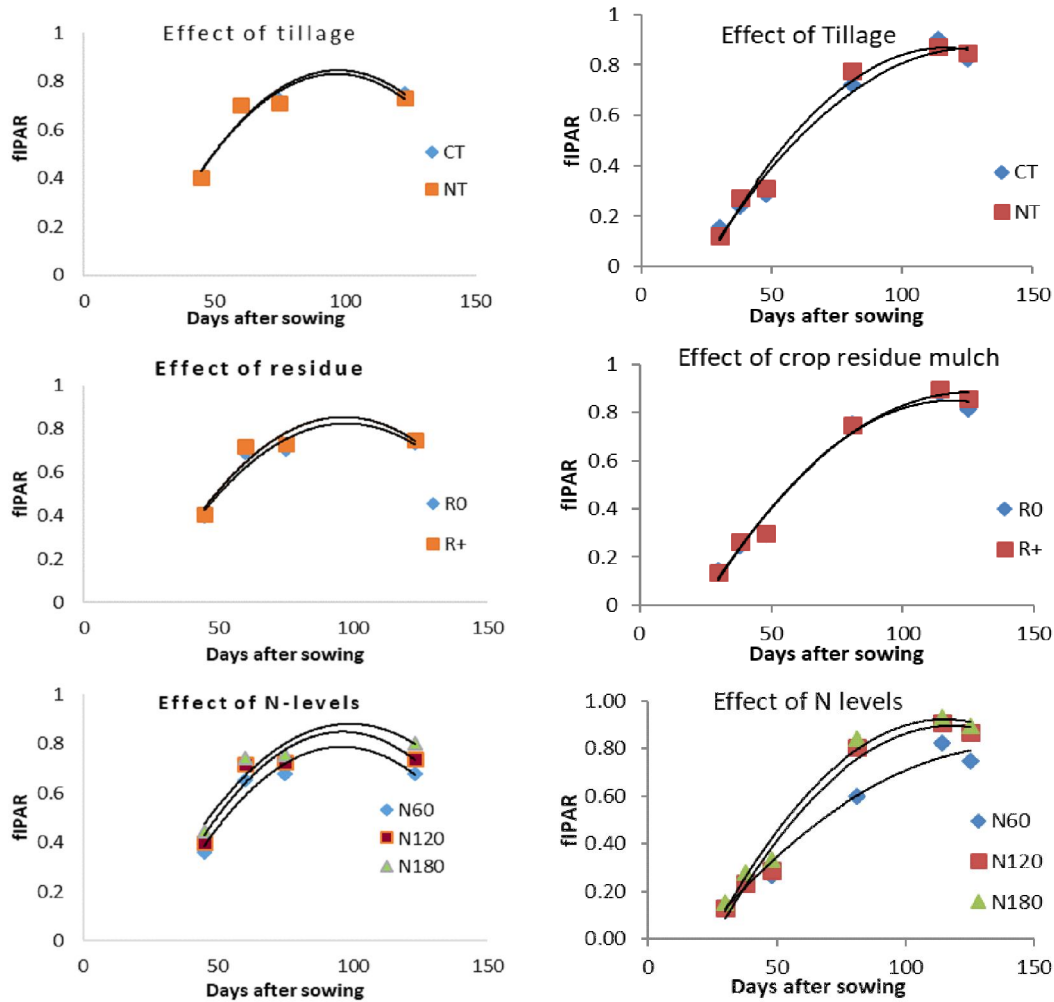


Fig.3: Effect of tillage, crop residue mulch and nitrogen levels on fraction intercepted photosynthetically active radiation (fIPAR) of wheat for 2017-18 and 2018-19

N180 increased over N120 and N60 treatments by 23 and 58%, respectively during 2017-18 and by 24.9 and 75.2%, respectively during 2018-19. Similarly application of 120 kg N ha⁻¹ significantly increased LAD (by 27.9 and 40.3% in 2017-18 and 2018-19, respectively) than that of 60 kg N ha⁻¹.

Extinction coefficient (*k*)

Extinction coefficient (*k*) varied from 0.46 to 0.59 during 2017-18 and from 0.41 to 0.504 during 2018-19 (Fig. 3), which is within the range of reported *k* values (0.41-0.78) for bread wheat (Yunusa *et al.*, 1993). There was no significant difference among tillage and residue management with respect to extinction coefficient but lower *k* values due to application of residues indicate the tendency of more horizontal leaf distributions over no mulch treatments. Averaged over tillage and residue management, extinction coefficient due to 60, 120 and 180 kg N ha⁻¹ were 0.59, 0.53

and 0.46, respectively during 2017-18 while during 2018-19, it was 0.46, 0.46 and 0.44, respectively. Decrease in *k* with increasing N level is in agreement with earlier findings (Brekke *et al.*, 2011; Bassu *et al.*, 2011; Saha *et al.*, 2015).

Grain yield and biomass yield of wheat

During the years 2018-19 the average grain as well as biomass yields (Table 2) was higher than that of the year 2017-18 due to more rainfall and lower temperature during crop growth seasons of 2018-19. Although, grain and biomass yield were not significantly influenced by either tillage or CRM but was significantly influenced by N-levels during both the years of study. Under N180 respectively 7.2 and 35.5% higher grain yield and 9.9 and 35.8% higher biomass yields were recorded over N120 and N60 during the year 2017-18. Similarly, during 2018-19 10.1 and 41.1% higher grain yields and 7.9 and 33% higher biomass yields were recorded under N180 than N120 and N60, respectively.

Table 2: Grain yield and Biomass yield of wheat as influenced by tillage, residue and nitrogen management

Treatment	Grain yield (kg ha ⁻¹)		Biomass yield (kg ha ⁻¹)	
	2017-18	2018-19	2017-18	2018-19
Effect of tillage				
CT	2778 ^A	3444 ^A	6778 ^A	9624 ^A
NT	2577 ^A	3630 ^A	6822 ^A	10141 ^A
Effect of residues				
R ₀	2623 ^A	3530 ^A	6794 ^A	9869 ^A
R ₊	2732 ^A	3545 ^A	6806 ^A	9896 ^A
Effect of Nitrogen				
N ₆₀	2220 ^C	2873 ^C	5675 ^C	8320 ^C
N ₁₂₀	2805 ^B	3684 ^B	7017 ^B	10258 ^B
N ₁₈₀	3008 ^A	4054 ^A	7708 ^A	11069 ^A
Effect of Tillage × Residue × Nitrogen				
CTR ₀ N ₆₀	2133 ^a	2783 ^a	5500 ^a	8500 ^a
CTR ₀ N ₁₂₀	2901 ^a	3256 ^a	7000 ^a	9728 ^a
CTR ₀ N ₁₈₀	3027 ^a	3978 ^a	7500 ^a	10309 ^a
CTR ₊ N ₆₀	2457 ^a	3015 ^a	6000 ^a	8471 ^a
CTR ₊ N ₁₂₀	2951 ^a	3729 ^a	7000 ^a	9696 ^a
CTR ₊ N ₁₈₀	3201 ^a	3902 ^a	7667 ^a	11038 ^a
NTR ₀ N ₆₀	2118 ^a	2698 ^a	5267 ^a	7663 ^a
NTR ₀ N ₁₂₀	2683 ^a	4095 ^a	7333 ^a	11335 ^a
NTR ₀ N ₁₈₀	2879 ^a	4366 ^a	8167 ^a	11678 ^a
NTR ₊ N ₆₀	2171 ^a	2996 ^a	5933 ^a	8646 ^a
NTR ₊ N ₁₂₀	2685 ^a	3656 ^a	6733 ^a	10273 ^a
NTR ₊ N ₁₈₀	2926 ^a	3971 ^a	7500 ^a	11249 ^a

Values in a column followed by same letters are not significantly different at $p < 0.05$ as per DMRT ; The uppercase letters and the lower case letters are used for comparing main plot and subplot effects, respectively

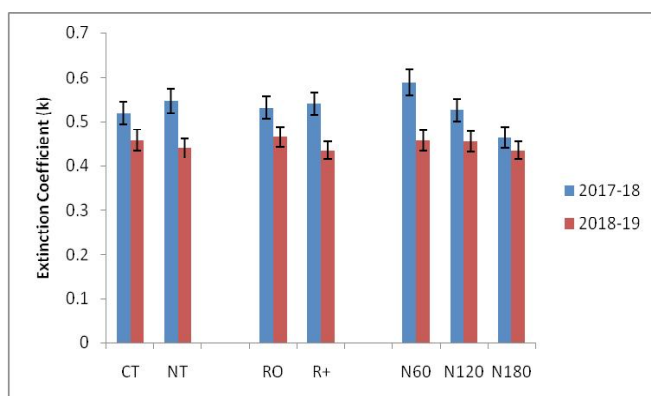


Fig.4: Extinction coefficient of wheat as influenced by tillage, crop residue mulch and N levels

Under N120, there was significant increase in grain yield (by 26.3% during 2017-18 and by 28.2% during 2018-19) and biomass yield (by 23.6% during 2017-18 and 23.3% during 2018-19) over N60 during both the years. However, contrary to the present study, it was reported that conservation agriculture practice could increase yield from second year onwards (Jat *et al.*, 2014) or after three years of cropping (Zhang *et al.*, 2009) by some workers. The interaction among tillage, residue and N-doses were not significant on grain and biomass yield of wheat.

Fraction intercepted photosynthetically active radiation (fIPAR)

The temporal variation of fIPAR for the years 2017-

Table 3: TIPAR and RUE of wheat as influenced by tillage, residue and nitrogen management

Treatment	TIPAR (MJ m ⁻²)		RUE (g MJ ⁻¹)	
	2017-18	2018-19	2017-18	2018-19
Effect of tillage				
CT	663.4	591.6	1.02 ^A	1.62 ^A
NT	674.3	606.3	1.01 ^A	1.67 ^A
Effect of residues				
R ₀	647.9	592.4	1.04 ^A	1.66 ^A
R ₊	689.8	605.5	0.99 ^A	1.63 ^A
Effect of Nitrogen				
N ₆₀	608.2	529.7	0.93 ^C	1.57 ^B
N ₁₂₀	693.0	618.2	1.02 ^B	1.66 ^A
N ₁₈₀	705.3	649.1	1.09 ^A	1.70 ^A
Effect of Tillage × Residue × Nitrogen				
CTR ₀ N ₆₀	610.8	540.2	0.90 ^a	1.57 ^a
CTR ₀ N ₁₂₀	660.5	599.3	1.06 ^a	1.62 ^a
CTR ₀ N ₁₈₀	693.5	617.3	1.08 ^a	1.67 ^a
CTR ₊ N ₆₀	620.6	554.7	0.97 ^a	1.53 ^a
CTR ₊ N ₁₂₀	669.2	595.0	1.05 ^a	1.63 ^a
CTR ₊ N ₁₈₀	725.9	643.3	1.06 ^a	1.72 ^a
NTR ₀ N ₆₀	585.7	483.4	0.90 ^a	1.59 ^a
NTR ₀ N ₁₂₀	650.5	630.4	1.13 ^a	1.80 ^a
NTR ₀ N ₁₈₀	686.2	684.1	1.19 ^a	1.71 ^a
NTR ₊ N ₆₀	615.5	540.5	0.96 ^a	1.60 ^a
NTR ₊ N ₁₂₀	792.0	647.9	0.85 ^a	1.59 ^a
NTR ₊ N ₁₈₀	715.8	651.8	1.05 ^a	1.73 ^a

Values in a column followed by same letters are not significantly different at $p < 0.05$ as per DMRT ; The uppercase letters and the lower case letters are used for comparing main plot and subplot effects, respectively.

18 and 2018-19 (Fig. 3) followed a trend similar to that of LAI. This finding is in agreement with Serrano *et al.* (2000). The maximum fIPAR under CT was higher (by 2.7% in 2017-18 and 3.3% in 2018-19) than that under NT. Similarly maximum fIPAR under CRM was higher than no mulch treatments by 2.3 and 2.0% in 2017-18 and 2018-19, respectively. This showed that application of crop residue mulch could enhance radiation interception probably due to better leaf area productions. With increase in N-doses, maximum fIPAR increased in both the years. This finding is in agreement with Pradhan *et al.* (2018).

Total Intercepted Photosynthetically Active Radiation (TIPAR) and Radiation Use Efficiency (RUE) of Wheat

The TIPAR and RUE of wheat was not significantly

affected by tillage and residue managements but increased significantly with increasing N-doses (Table 3). TIPAR in N180 was higher than N60 by 16 and 22.5% in 2017-18 and 2018-19, respectively. Similarly, RUE in N180 was higher than N60 by 17.2 and 8.3% during 2017-18 and 2018-19, respectively. During the year 2017-18, RUE under N180 was significantly higher than that of N120 by 6.9% whereas during the year 2018-19, there was no significant difference in RUE due to N120 and N180. Higher TIPAR with increasing N-level was due to higher LAI at higher N-levels (Bassu *et al.*, 2011; Pradhan *et al.*, 2018). Higher RUE at higher N-levels is in agreement with Pradhan *et al.* (2014) which may be due to higher LAD at higher N-levels. The interaction of tillage, residue and N-management was not significant on TIPAR and RUE of wheat in both the years.

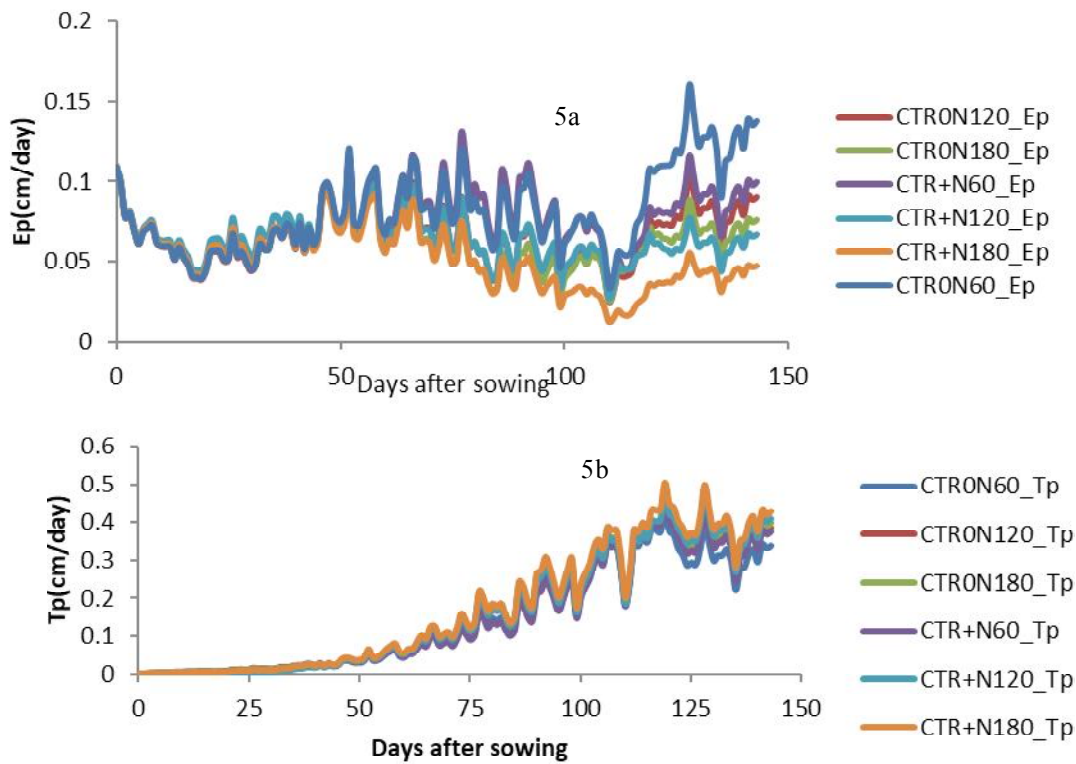


Fig.5: Potential evaporation (Ep)(5a) and Potential transpiration (Tp) (5b) rate (cm day⁻¹) of wheat as influenced by crop residue mulch and N levels under conventional tillage during the year 2018-19

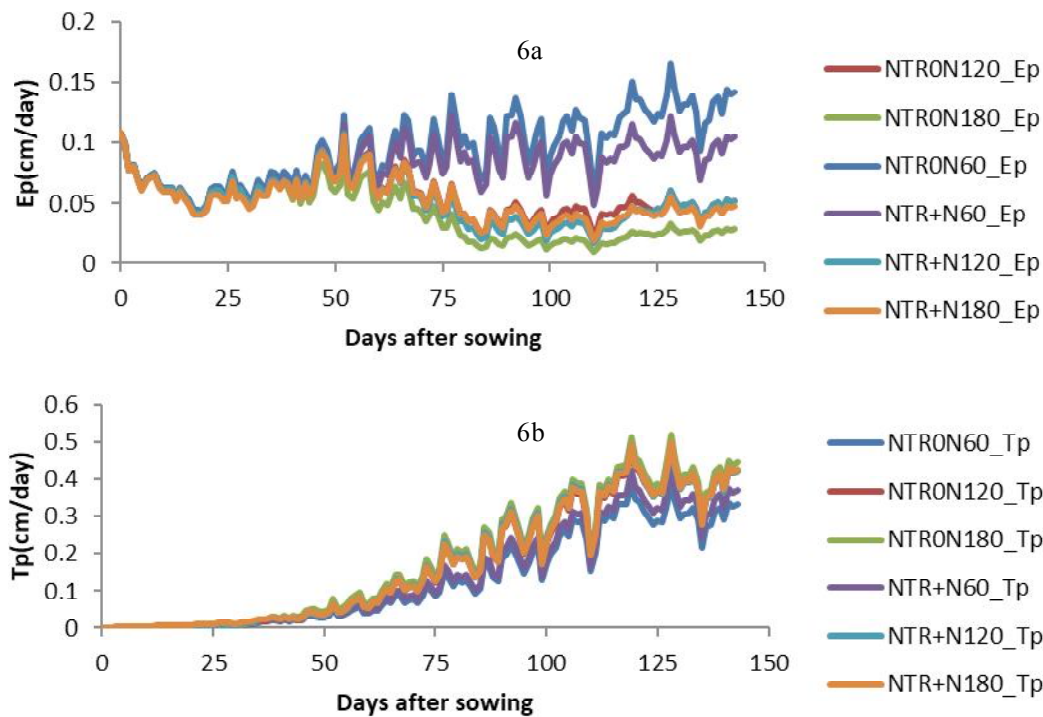


Fig.6: Potential evaporation (Ep) (6a) and Potential transpiration (Tp) rate (cm day⁻¹) (6b) of wheat as influenced by crop residue mulch and N levels under No tillage during the year 2018-19.

Soil evaporation (E_p) and crop transpiration rate (T_p)

Temporal variation in soil evaporation (E_p) and crop transpiration (T_p) under different tillage, residue and N-management for the year 2018-19 is depicted in Fig 5 and Fig. 6, respectively. Averaged over residue and N-management, E_p under NT was less (by 6%) and T_p was higher (by 2.6%) than that of CT. Similarly averaged over tillage and N-management E_p was reduced by 5.6% and T_p was increased by 2.4% under CRM than that of no mulch treatments. Under crop residue mulch lower evaporation loss was due to less radiation interception at the soil surface and higher transpiration was due to better hydrothermal regime and better crop growth. With the increase in N-dose, potential evaporation decreased while the potential transpiration increased. This may be attributed to the fact that a nitrogen-deficient crop has high evaporation/transpiration ratio associated with small canopies (Caviglia and Sadras, 2001; Norton and Wachsmann, 2006).

CONCLUSION

From this study it may be concluded that residue mulching is an effective strategy to improve the crop transpiration (T_p) by reducing the soil evaporation (E_p) losses and thus can improve yield of wheat. This has also potential to increase the maximum leaf area index and leaf area duration. With the increase in N dose there was increase in LAI, LAD, TIPAR, grain yield, RUE and T_p but decrease in E_p . So, conservation agricultural practices *i.e.*, No tillage with crop residue mulching and 150% of the recommended dose of nitrogen has the potential to improve radiation interception, radiation use efficiency and grain yield of wheat in the North-west plain region of India.

ACKNOWLEDGEMENT

The first author acknowledges the help received from IARI in the form of Fellowship during the study period. The logistic support received from the Director, IARI during the study period is thankfully acknowledged.

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